ASD TR 7-888 (VIII)

ASD INTERIM REPORT 7-888 (VIII)
April 1964

Development of ULTRASONIC WELDING EQUIPMENT for REFRACTORY METALS

by
Nicholas Maropis

AEROPROJECTS INCORPORATED
West Chester, Pennsylvania

Contract: AF 33(600)-43026
ASD Project No. 7-888

Interim Technical Progress Report

January through March 1964

Design, development, and construction of the 25-kilowatt spot-type welding machine has continued.

FABRICATION BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

AFSC Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT-SUMMARY
Interim Technical Progress Report

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DEVELOPMENT

OF

ULTRASONIC WELDING EQUIPMENT

FOR

REFRACTORY METALS

Nicholas Maropis
Aeroprojects Incorporated

Design, development, and construction of the 25-kilowatt spot-type welding machine has continued.

Experience gained during the evaluation of ceramic transducer assemblies was used to design a 4.2-kilowatt unit. This assembly incorporates all the modifications previously found desirable to improve the electrical characteristics and facilitate heat removal from the ceramic elements.

An extensive study of the test model of the overhung-coupler geometry revealed the factors contributing to its unsatisfactory behavior, and necessary modifications are being made.

Assembly of the 25-kilowatt power source was completed and acceptance tests were conducted by Aeroprojects personnel. The equipment performance was satisfactory, and the complete assembly was delivered to Aeroprojects.

Installation of welder control components on the 25-kilowatt welder frame was completed.

end
end

FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-43026 from January 1, 1964 through March 31, 1964. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with Aeroprojects Incorporated of West Chester, Pennsylvania, was initiated under ASD Manufacturing Technology Project 7-888, "Development of Ultrasonic Welding Equipment for Refractory Metals." It was administered under the direction of Fred Miller of the Fabrication Branch (ASRCTF), Manufacturing Technology Laboratory, AFSC Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

This project is under the direction of J. Byron Jones, with Nicholas Maropis serving as Project Engineer. Others associated with the program are Carmine F. DePrisco, Chief Electronics Engineer; John G. Thomas, Metallurgist; Janet Devine, Physicist; Jozef Koziarski, Ultrasonic Welding Laboratory Director; and W. C. Elmore, Consultant. This document has been given the Aeroprojects internal report number of RR-64-35, and is an interim report. Information reported herein is preliminary, and subject to further analysis and modification as the work progresses.

The methods used to demonstrate a process or technique on a laboratory scale are usually inadequate for use in production operations. The objective of the Air Force Manufacturing Methods Program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. The program encompasses the following technical areas:

Rolled Sheet
Forgings
Extrusions
Castings
Fiber
Fuels and Lubricants
Ceramics and Graphites
Nonmetallic Structural Materials

Powder
Component Fabrication
Joining
Forming
Material Removal
Solid-State Devices
Passive Devices
Thermionic Devices

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated. Direct any reply concerning the above matter to the attention of Mr. W. W. Dismuke, ASRKRA.

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PUBLICATION REVIEW

Approved by: J Byron Jones
J. Byron Jones

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Phase II

INTRODUCTION

Since ultrasonic welding was first demonstrated as a practical method for joining thin gages of aluminum and other common metals and alloys, the equipment capability has been continuously extended to joining materials of increasing thickness as well as newer metals and alloys that are difficult or impossible to weld by other techniques. The aerospace need for high-temperature, corrosion-resistant, refractory metals and alloys has emphasized the need for ultrasonic welding machines of greater capability than are now available.

The objective of this program is to design, assemble, and evaluate heavy-duty ultrasonic welding equipment for joining refractory materials and superalloys in thicknesses up to 0.10 inch, and to develop necessary techniques for producing reliable welds in these materials. The accomplishment of this objective is divided into three phases: Phase I is concerned with establishing feasibility, defining problem areas, and delineating appropriate solutions thereto. Phase II embraces the development of the required equipment and techniques. Under Phase III, the performance characteristics of the ultrasonic welding equipment will be demonstrated.

Under Phase I, completed prior to the current reporting period (2)*, the feasibility of producing ultrasonic welds in both monometallic and bimetallic combinations of Cb(D-31), Mo-0.5Ti, Inconel X-750, PH15-7Mo stainless steel, Rene 41, and tungsten was demonstrated. By extrapolating the weldable gage capability of 4-kilowatt and 8-kilowatt ultrasonic spot-type welders, and utilizing a previously developed first-approximation criterion for the energy required to weld materials of various hardnesses and thicknesses, the electrical power input to the transducer necessary to join the above materials in gages up to 0.10 inch was estimated as approximately 25 kilowatts.

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* Numbers in parentheses refer to List of References at end of report.

Also under Phase I, problems involved in the production of heavy-duty ultrasonic welding equipment were delineated, a systematic approach to solving these problems was outlined, and requirements for the requisite heavy-duty spot-welding equipment were defined. Basic concepts involved in such machines were investigated, and spot-type welders for high-power operation were studied in considerable detail. Theoretical and experimental information was evolved to support the design requirements for this type of machine.

A survey of the "state of the technology" of transducer materials and coupler materials, supplemented by laboratory investigations, evinced that the transducer-coupling system for the heavy-duty equipment should preferably utilize lead-zirconate-titanate ceramic transducers, and coupling members made of aluminum-bronze, K Monel, or beryllium-copper. The requisite vibratory power can be delivered to the weld zone by means of an opposition-drive transducer-coupling system.

Ultrasonic welding of the refractory metals during the course of this program, and subsequent work involving refractory metals on concurrent programs, have indicated the suitability of Astroloy and Udimet 700 alloys as tip materials.

Preliminary studies showed that the transducer-coupling systems could be driven by either a motor-alternator or an electronic generator providing about 25 kilowatts of 15-kilocycle electrical power. If the motor-alternator were selected, solid-state elements would be considered to meet the switching requirements.

The work initiated under Phase II has the following objectives:

1. Develop the necessary methods, techniques, and equipment to ultrasonically join the selected materials.

2. Design and construct ultrasonic joining unit(s) in accordance with the approach outlined in Phase I.

3. Develop methods and techniques to demonstrate the capability of the equipment developed under Phase II to join the selected materials.

This report describes the work accomplished during the period from January 1 through March 31, 1964. Special attention was given to evaluation of primary equipment elements required in the 25-kilowatt ultrasonic spot-type welding equipment, including testing of the modified tension-shell ceramic transducer and of a single-element portion of the projected acoustical coupling system, plus incorporation of control components into the welder frame. The third item above, equipment capability studies, cannot be pursued until after equipment assembly has been completed.

I. MATERIAL INVESTIGATIONS

Material investigations requisite to fulfillment of Phase II were essentially completed prior to this reporting period and no further work in this area is anticipated until the 25-kilowatt welder is operating. The status of these investigations is summarized in the preceding quarterly report (1).

II. EQUIPMENT DEVELOPMENT

The tension-shell ceramic transducer has evolved from the original concept to its present design through several problem solutions. The acoustic problems associated with the generation and transmission of high levels of vibratory power are implicitly associated with the mechanical, electrical, and thermal problems presented by the assembly. A bias stress is necessary to the successful operation of ceramic-transducer elements at high power levels. Not only must the assembly maintain this predetermined level of bias stress under all expected operating conditions, but the mechanics of the transducer assembly must not provide a sink for significant amounts of vibratory energy.

With the 3.3-kilowatt test unit, which incorporated standard "V" type threads between the tension shell and the end sections, it was found that, at higher power levels, vibratory energy was being degraded to heat by motion in these threads. This condition was improved by changing to buttress-type threads (1° positively inclined load-bearing face) which permitted continuous operation up to about 1200 watts and pulse operation up to about 2400 watts before substantial heating occurred at the thread joints.

During this period, the buttress-thread design was modified to incorporate a 7° negatively inclined load-bearing face which further reduced the motion in the threads, and continuous operation at 2000 watts input power produced only slight heating in the thread area. The various thread configurations are shown in Figure 1.

The larger 4.2-kilowatt final design assembly incorporates this change as well as the previously reported (1) modifications to improve electrical characteristics and facilitate heat removal from the ceramic elements. It is anticipated that pulse operation for spot-type welding will be satisfactory at the full power output of this assembly.

The original test transducer components (tension shell, end sections, and spacers) were made of beryllium-copper alloy because of its low loss characteristics during transmission of vibratory power (2). This alloy, however, is characterized by a relatively low velocity of sound (approximately 3800 meters per second) and consequently a short wavelength. The complete assembly of ceramic elements, metal heat-exchanger wafer, and electrical conducting plates thus constituted an undesirably large fraction of a wavelength, because the ceramic "drive" constitutes too large a proportion of the 1/2 wavelength. After operating experience it was decided to use Monel K-500, which is characterized by a higher velocity of sound (4500 meters per second), and which also possesses good acoustic transmission characteristics for fabrication of the larger units.

Monel K-500 is a high-strength, corrosion-resistant alloy which can be satisfactorily machined with reasonable care, to an ordinary geometry, but requires extra care for unusual geometries (3). In the design for the large transducer, the negatively inclined load-bearing face of the modified buttress thread (Figure 1), which was designed for a precision fit (1), required simultaneous machining of the load and relief thread surfaces. Under these conditions, rolling and tearing of the Monel occurred rather than smooth cutting, as shown in the photograph of Figure 2. Such threads would clearly experience fatigue failure under high-stress cyclic loading, and were therefore judged not suitable.

The efforts to solve this problem introduced a delay in the test schedule for the first large transducer. The first 4.2-kilowatt beryllium-copper transducer was fabricated and assembled ready for evaluation.

TRANSDUCER-COUPLING SYSTEM

Careful study of the test model of the overhung-coupler system revealed second order factors contributing to its unsatisfactory behavior (1). Two of these factors were associated with the requirement for mechanically removable welding tips (1) and the generation of undesirable flexural waves during high-power operation. The latter was unexpected since the basic design has been used with outstanding success on a high power ultrasonic line-welding machine for producing can-body side seams with a single weld pulse.

The flexural waves apparently resulted from an interaction between the transverse motion associated with Poisson's ratio and the static force application arm. Causative factors of this secondary flexural wave are indicated in the sketch of Figure 3. Modifications to the couplers are in process to verify this tentative conclusion. The final coupling systems will not be completed until these problems are resolved.

Further study has indicated that an additional contributing factor is associated with the cross-sectional geometry of the coupler and spherical welding tip at the point of force application. Application of clamping force causes the coupler to rotate slightly about its neutral axis,

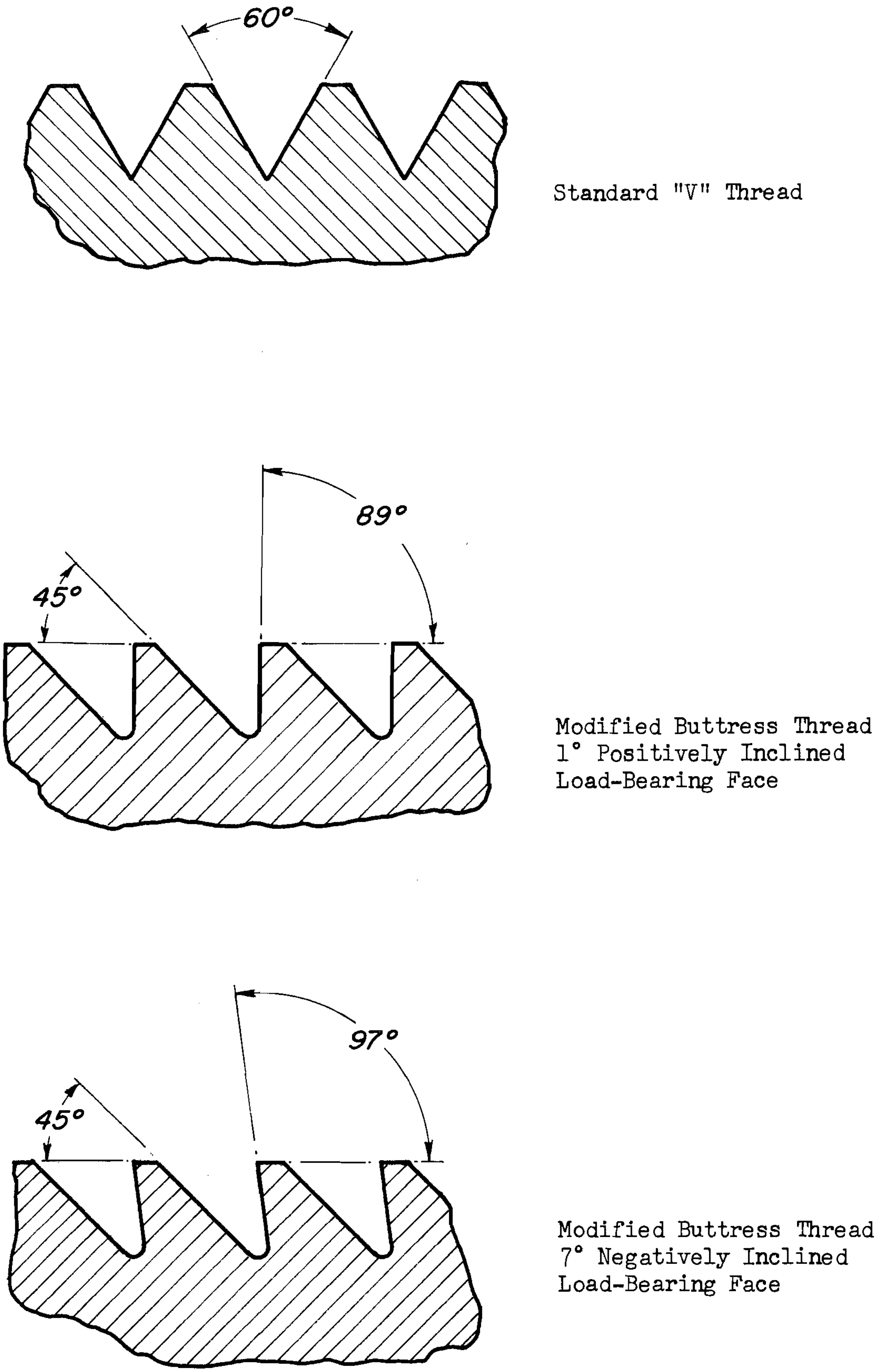

Figure 1

THREAD CONFIGURATIONS USED FOR THE CERAMIC TRANSDUCER ASSEMBLY

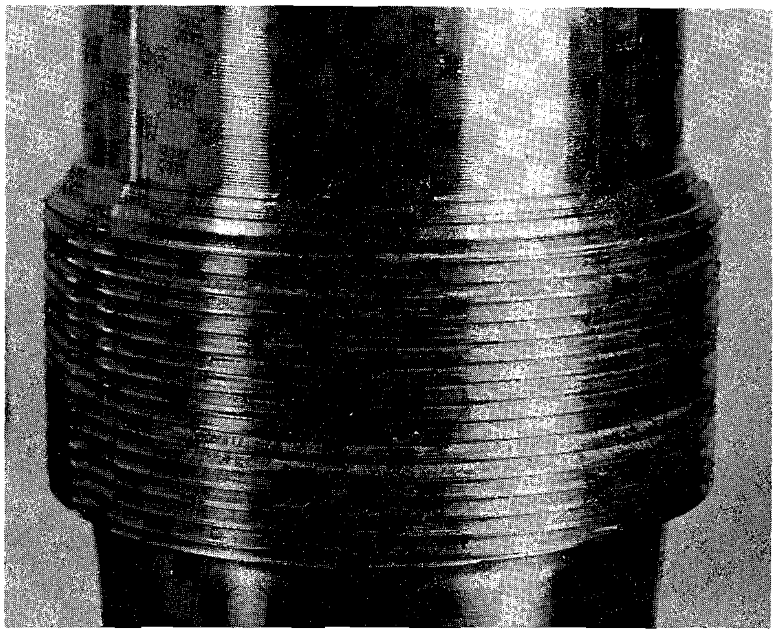

Figure 2

TORN THREADS OCCURRING DURING MACHINING OF MONEL K-500 TRANSDUCER COMPONENTS

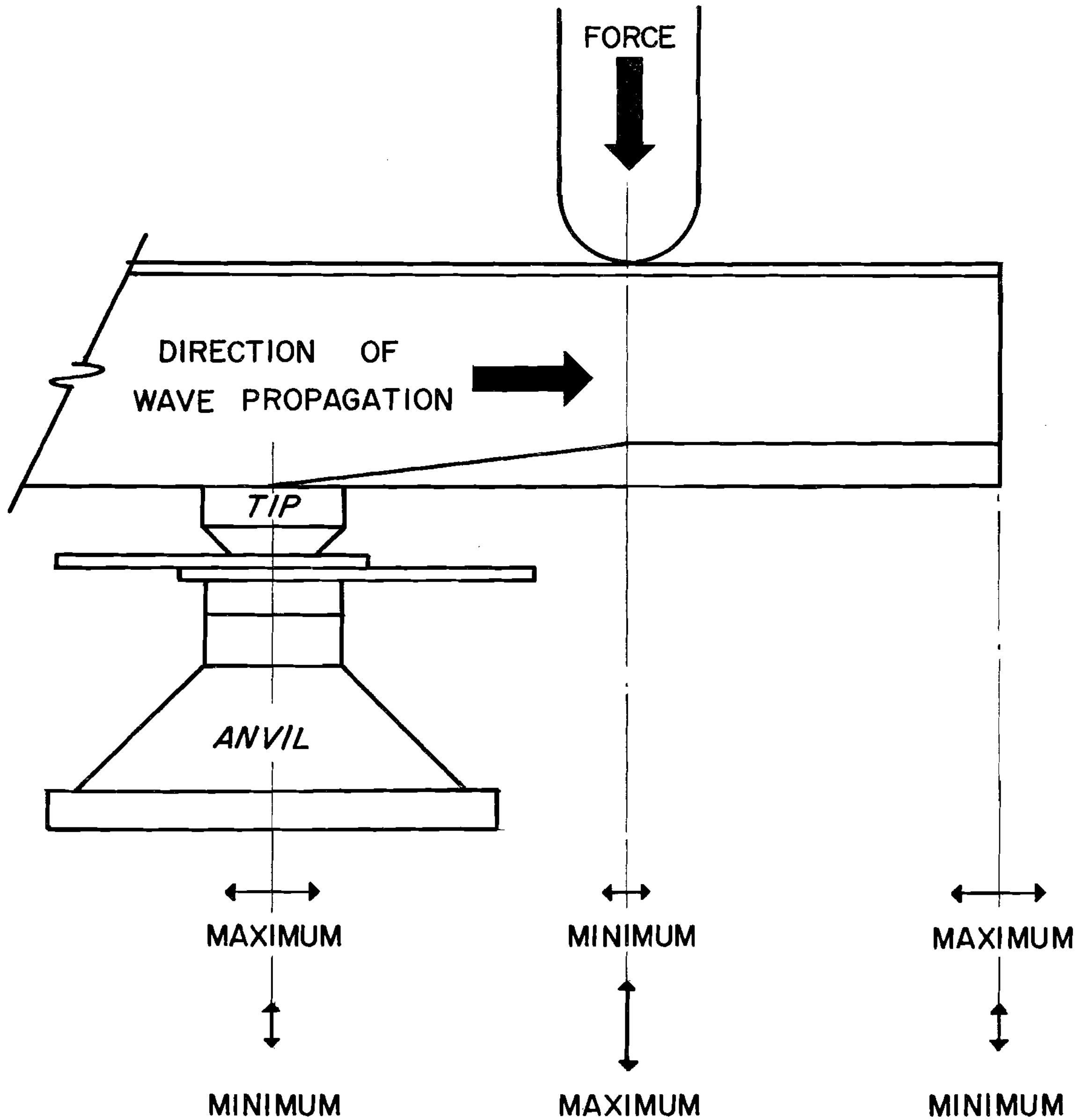

Figure 3

MECHANISM OF SECONDARY FLEXURAL WAVE IN LATERAL-DRIVE WELDING SYSTEM with the contact area of the spherical welding tip acting as a pivot (Figure 4-A). This problem was eliminated by replacing the spherical tip with an elongated tip, but a spherical tip is required for the final machine. It appeared that the torsional stiffness of the section could be increased by incorporating a flat plate contact section, as shown in Figure 4-B, to which the force will be applied, thus eliminating this twist reaction. Measurements with this configuration are in progress and are indicative of success.

POWER SOURCE (Frequency Converter)

Assembly of the 25-kilowatt power source was completed by Fairchild Stratos Corp. and the equipment was moved to the Dayton T. Brown Testing Laboratories, Bohemia, Long Island, New York, where operation during off-peak hours was possible without exceeding the allowable peak-current load. Aeroprojects engineering personnel, accompanied by Frank Tutko, Industrial Specialist of the U. S. Air Force, Philadelphia Office, visited that facility on February 5, 1964, and carried out acceptance tests on the equipment.

The final assembly was comprised of a primary drive motor; variable speed differential transmission; a speed matching transmission with oil pump and heat exchanger for the oil; a high frequency alternator; and a supporting base for mounting the assembly.

The block diagram of Figure 5 shows the electromechanical train associated with the conversion of 60 cycle/second, 440-volt power to a nominal 15,000 cycles/second frequency-controllable 25-kilowatt ultrasonic power.

Figure 6 shows the equipment array for the necessary acceptance tests.

The power source was driven into a dummy load consisting of six 230-volt, 5000-watt Calrod heaters attached to the output terminals of the alternator in a parallel combination. Output power was computed on the basis of the resistance of the load (which was calculated and measured at 1.7 ohms) and measurements of the voltage across the heaters.

Line current and voltage were monitored with the instrumentation indicated in Figure 6. The output of a current transformer, consisting of four turns of instrument lead wire coiled around one leg of the power lines into the power source, was viewed on an oscilloscope and the relative values between peak, or starting current and running current were determined.

The frequency range of the power source assembly was determined by establishing Lissajous patterns between a precalibrated reference oscillator and the output of the alternator.

These data are summarized in Tables I, II, and III.

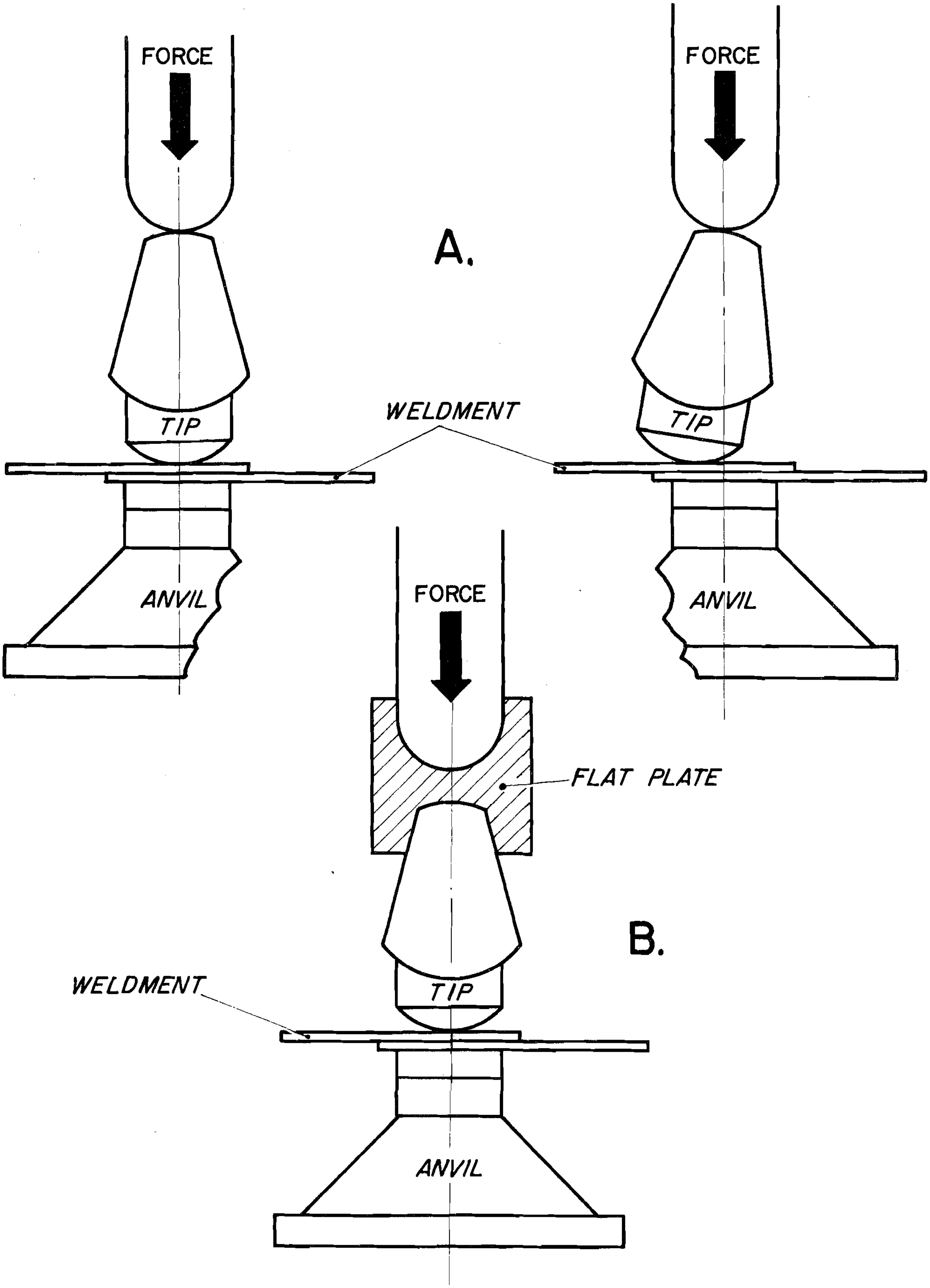

Figure 4

A. UNSTABLE CONDITION OF LATERAL-DRIVE WELDING SYSTEM

B. PROPOSED MODIFICATION TO LATERAL-DRIVE WELDING SYSTEM

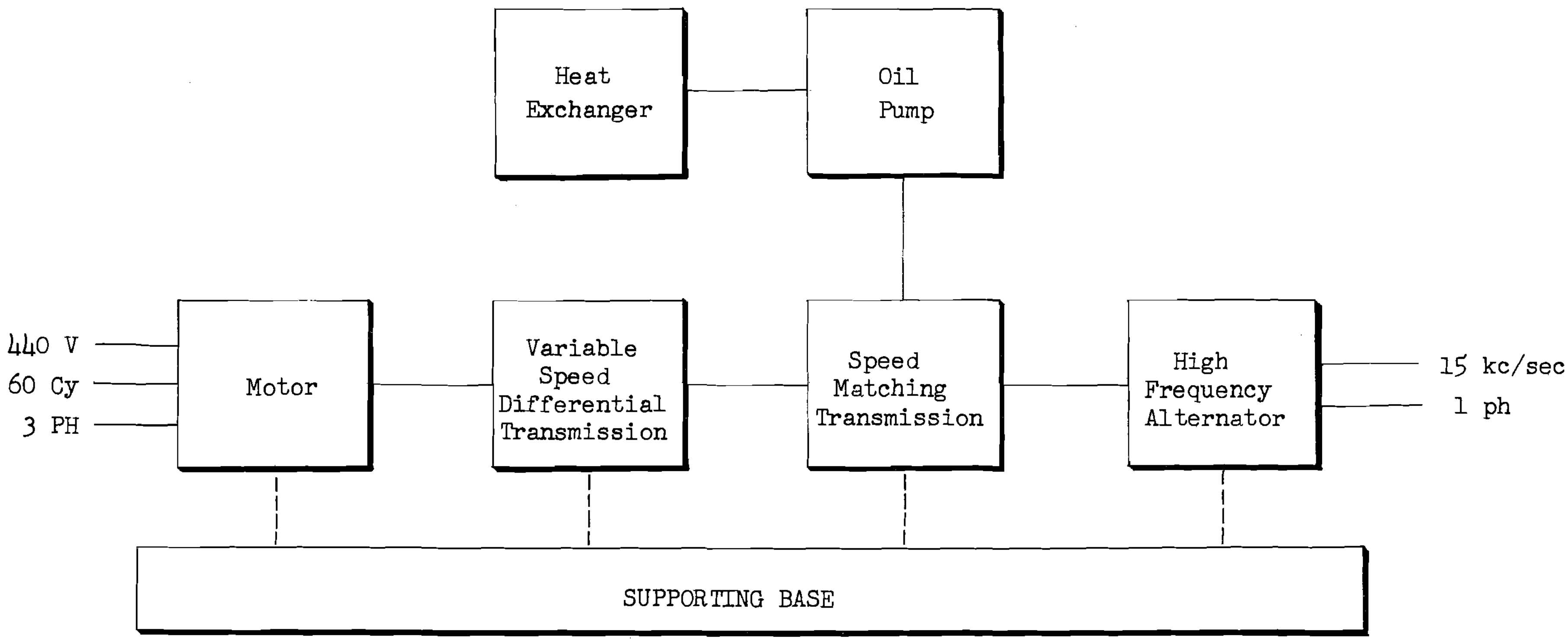

Figure 5

COMPONENTS OF 25-KILOWATT 15 KILOCYCLE POWER SOURCE

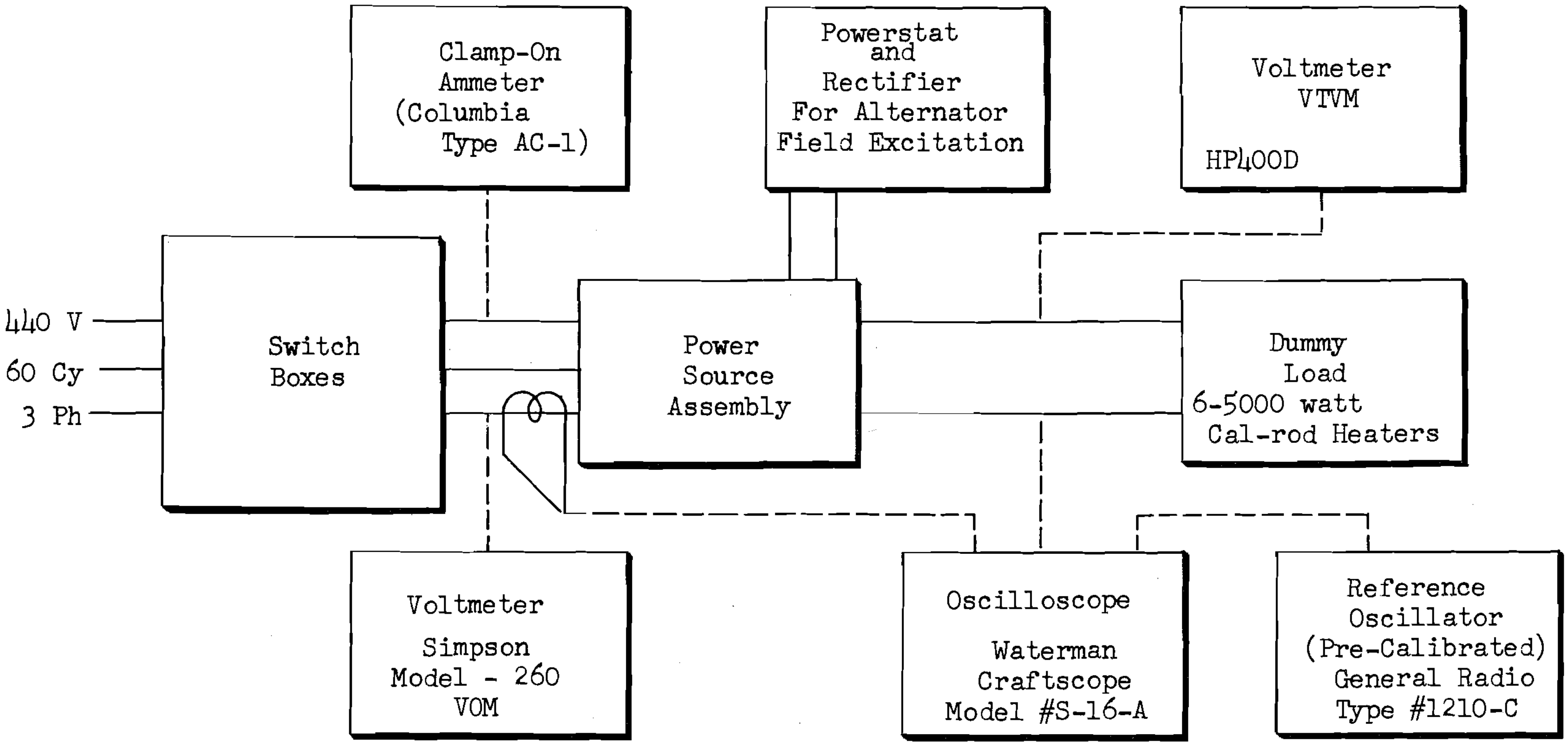

Figure 6

EQUIPMENT ARRAY FOR POWER SOURCE ACCEPTANCE TESTS

Table I

25 KW ALTERNATOR HIGH-FREQUENCY POWER SOURCE TESTS

	Requirements	Test	Differences
Power	30 kw (Max.)	35.3 kw	+5.3 kw
Alternator Shaft Speed as governed by Specon* and speed-matching transmissions			
Specon Shaft Speed(RPM)	2780 ± 3-1/2%		
Speed-matching Transmission Ratio	1:2.00	1:2.0217	+1.085%
Shaft Speed (RPM)	5750 to 5370	5820 to 5420	+70 RPM to 50 RPM
Alternator Frequency cycles per second	15520 to 14480	15700 to 14625	+180 CPS to 145 CPS
Alternator Inertia ($lb\ ft^2$)	161	165^x	+4

* Differential variable speed transmission

x Calculated

Table II

25 KW ALTERNATOR POWER SOURCE TESTS

Field Set Position	Current-amperes* Input Power Line: Line 1	Line 2	Line 3	Voltage Across Dummy Load: Volts	Approximate Power Into Load: Watts
0-(no field)	110	117	117	0	0
1	104	130	130	100	5650
2	120	140	130	142	13000
3	120	130	130	173	17000
4	140	155	150	210	25000
5	140	155	155	225	28700
6	---	---	---	250	35300

* Measurements were made with a clamp-on ammeter which is sensitive to orientation of the plane of the clamp jaws to the axis of the conductor.

Input line voltage - 465 V across phases.

Table III

30 KW ALTERNATOR TEST DATA

Motor 3 Ø - 440 v - 60 cycle	100 hp
Alternator and speed matching transmission (only)	
Friction and Windage losses	4.4 kw
Iron losses	7.1 kw
Power input at full power	46.0 kw
Output power	30.0 kw
Efficiency	65 %
No load torque at input to transmission	11 ft lbs
Differential Variable speed transmission	
Efficiency	80 %
No load - no field input power	5.5 kw
Full load input	58.0 kw
No load - max. field input	14.5 kw
Complete assembly	
Overall efficiency	51.8 %
A. No field - torque	21.6 ft lbs
B. With field - torque	57.0 ft lbs
C. 30 kw load - torque	227.0 ft lbs
A = 120 amps B = 125 amps C = 160 amps at	465 volts
Motor	
No load - no field	7.5 hp
No load - with field	19.5 hp
Full load	77.6 hp

The alternator power source assembly meets the requirements with the variations which were noted (1) for the alternator speed-matching transmission wherein it was determined that:

a. The total inertia of the alternator speed-matching transmission exceeded the $161\frac{1}{2}$ lb. ft^2 value originally requested by approximately 4 lb. ft^2.

b. The speed-matching transmission ratio was originally requested to be 1:2.00 and was delivered at 1:2.0217.

c. The no-load voltage of the alternator was 265 volts instead of the requested 250 volts.

The deviations from the originally established requirements noted above can be accommodated. The unit operates satisfactorily and is acceptable.

The complete assembly shown in Figure 7, was delivered to Aeroprojects on February 7, 1964.

MACHINE STRUCTURE AND CONTROL COMPONENTS

Assembly and installation of welder control components on the 25-kilowatt welder frame have been completed. Minor adjustments and instrument calibration will be made during the initial stages of equipment operation.

REFERENCES

1. Interim Report 7-888 (VII), February 1964.

2. Interim Report 7-888 (II), December 1961.

3. Technical Bulletin T-9, "Engineering Properties of Monel Alloys K-500 and 501." Huntington Alloy Products Division, The International Nickel Company, Inc., Huntington, West Virginia.

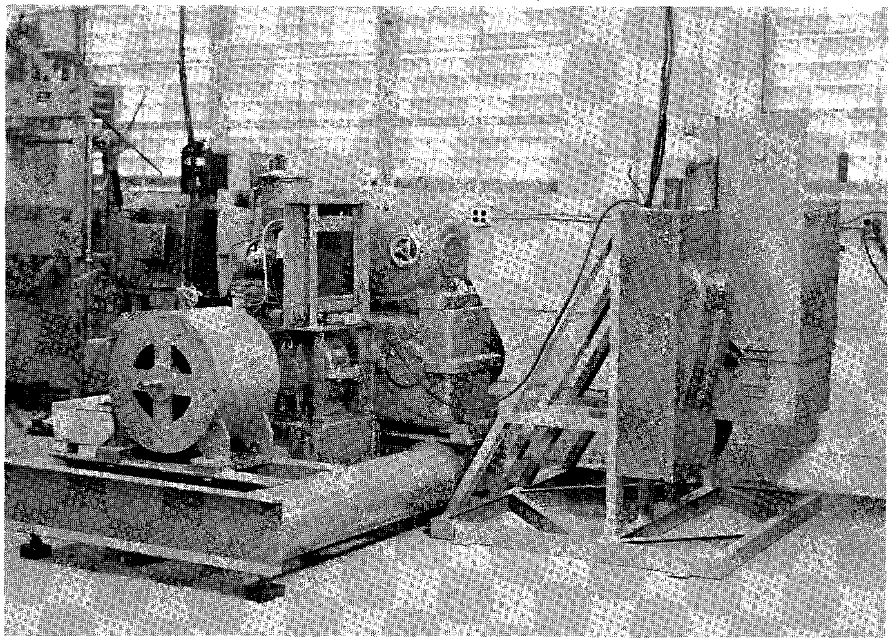

Figure 7

25-KILOWATT MOTOR-ALTERNATOR POWER SOURCE
FOR HEAVY-DUTY WELDER

DISTRIBUTION LIST

1 Acoustica Associates, Inc.
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2 Aerojet-General Corp.
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1 Chesapeake Instrument Corporation
Attn: Director Research & Development
Shadyside, Maryland

1 Chrysler Missile Division
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1 Curtiss-Wright Corp.
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1 North American Aviation, Inc.
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1 North American Aviation, Inc.
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1 Northrop Aircraft, Inc.
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1 Northrop Aircraft, Inc.
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1 Air Force Systems Command
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1 Aeronautical Systems Division
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2 Aeronautical Systems Division
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1 Aeronautical Systems Division
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2 Aeronautical Systems Division
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1 Battelle Memorial Institute
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1 Ballistic Missile Systems Division
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1 Chief, Bureau of Naval Weapons (PID-2)
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1 Temco Aircraft Corp.
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1 Union Ultra-sonics Corporation
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1 Vought Aeronautics Division
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1 Vought Aeronautics Division
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1 G. C. Marshall Space Flight Center
National Aeronautics & Space Administration
Attn: William A. Wilson
Chief, MR & D Branch
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2 Langley Research Center
National Aeronautics & Space Administration
Attn: Technical Director
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1 Scientific & Technical Information Facility
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1 Engelhard Industries
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